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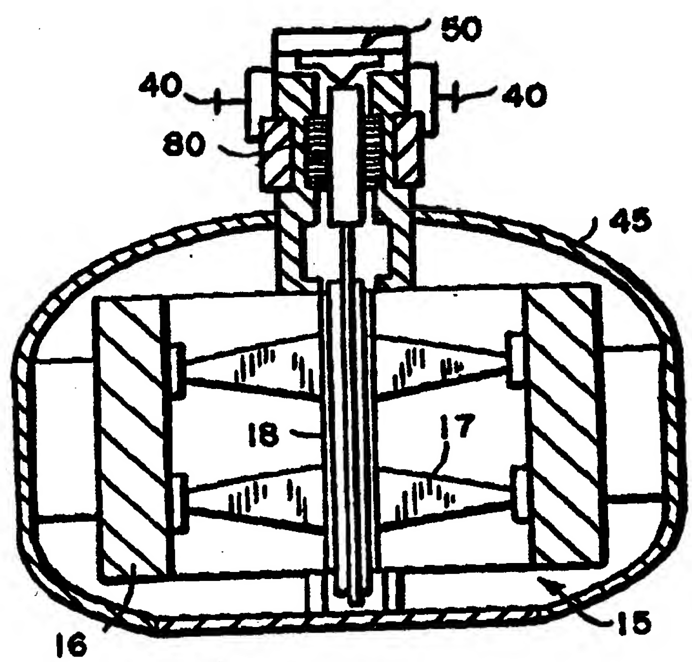
(54) Title: FLYWHEEL POWER SUPPLY

(57) Abstract

A power supply device for providing uninterrupted power for a period of time is disclosed. The power supply device has a controller and a flywheel device. The flywheel device has a housing (45) that contains a flywheel rotor (15) and a motor/generator (80) rotor. The flywheel rotor (15) and the motor/generator (80) rotor are mounted on a common shaft. An active axial magnetic bearing (50) is located to support the shaft for frictionless rotation. The bearing provides support for the shaft, the flywheel rotor (15) and motor/generator rotor (80). The axial magnetic bearing (50) is attached to the housing (45) and provides, in combination with the motor/generator (80) rotor, a flux path and a magnetic field to exert a magnetic force to lift the motor/generator (80) rotor and the shaft on which it is mounted.



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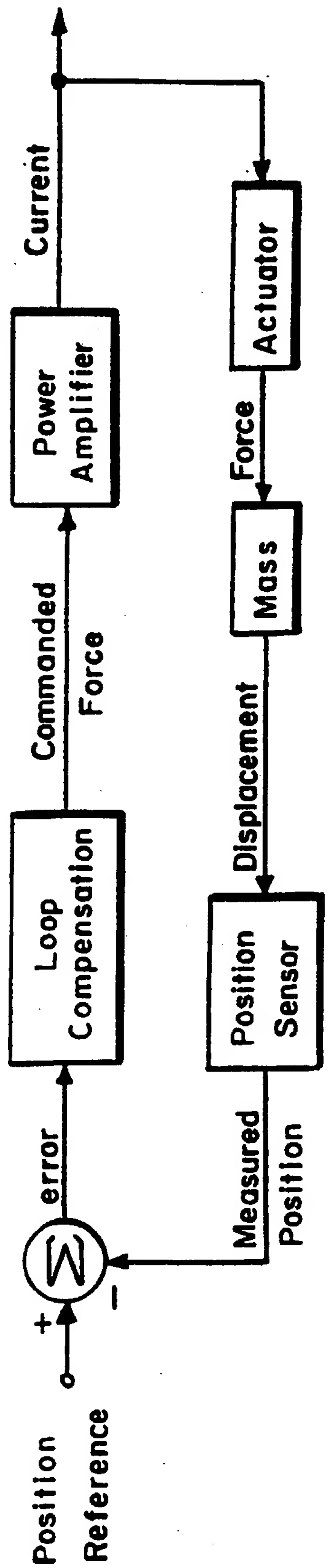
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FIG. 2

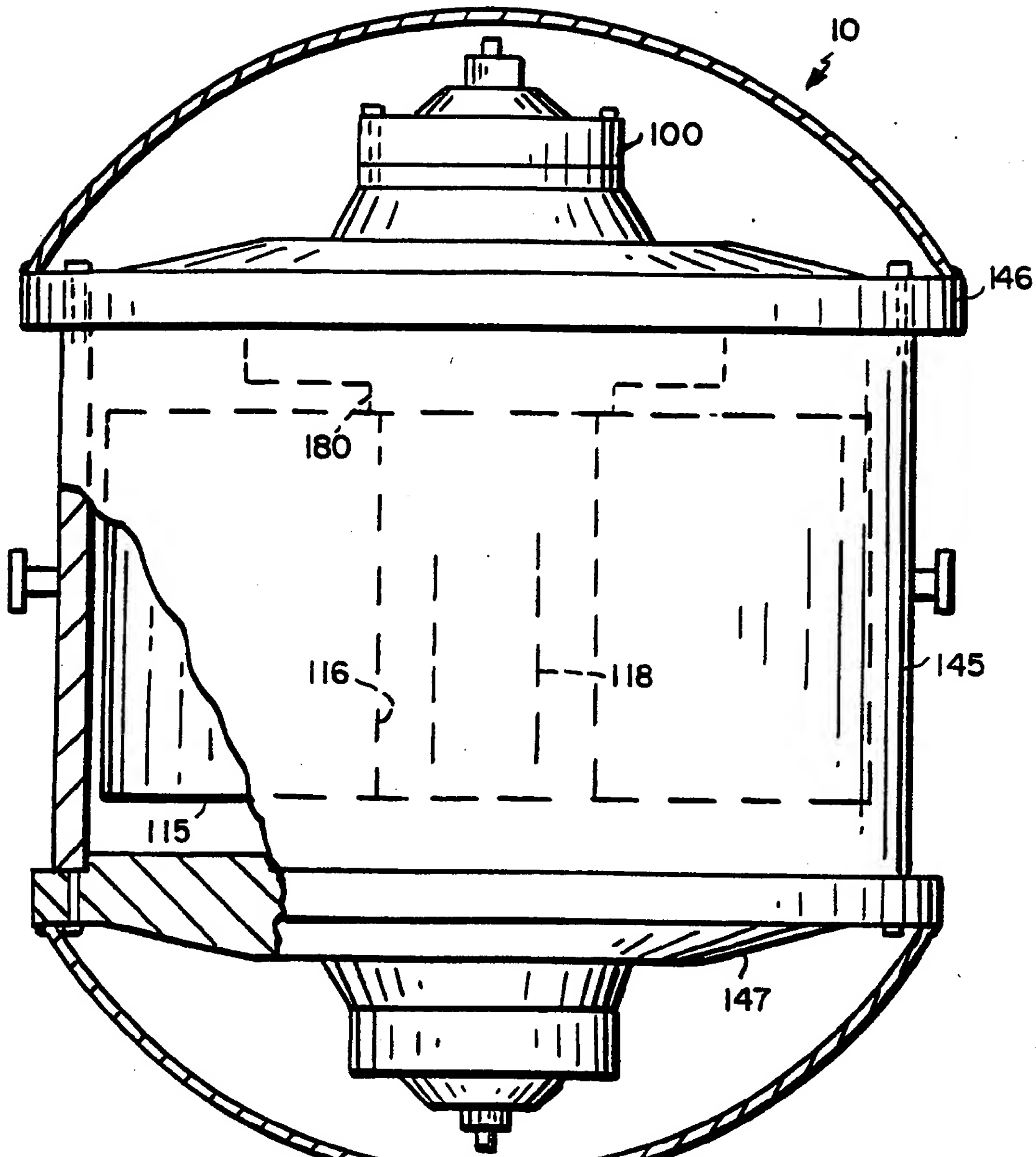

FIG. 3

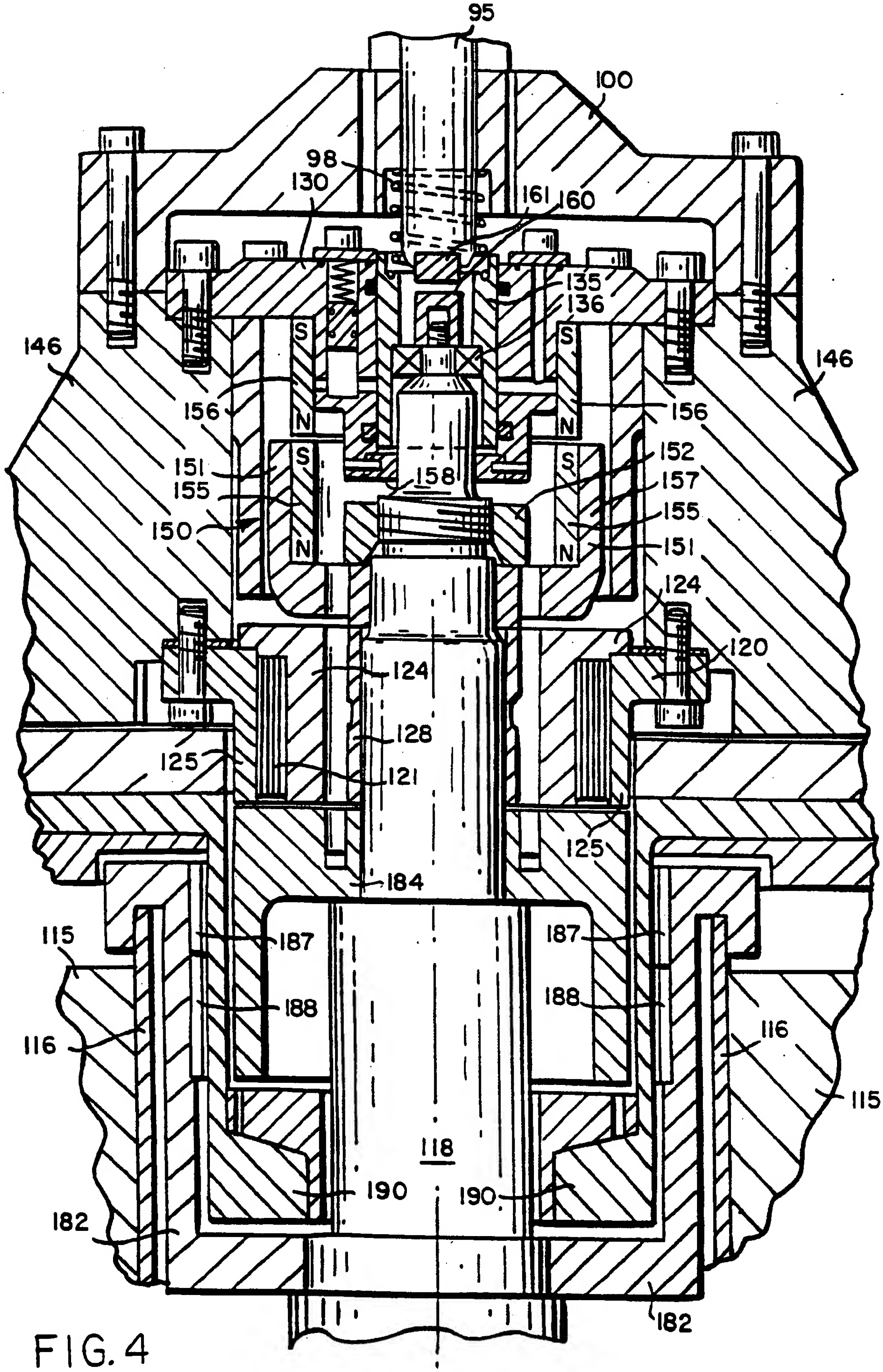
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FIG. 4

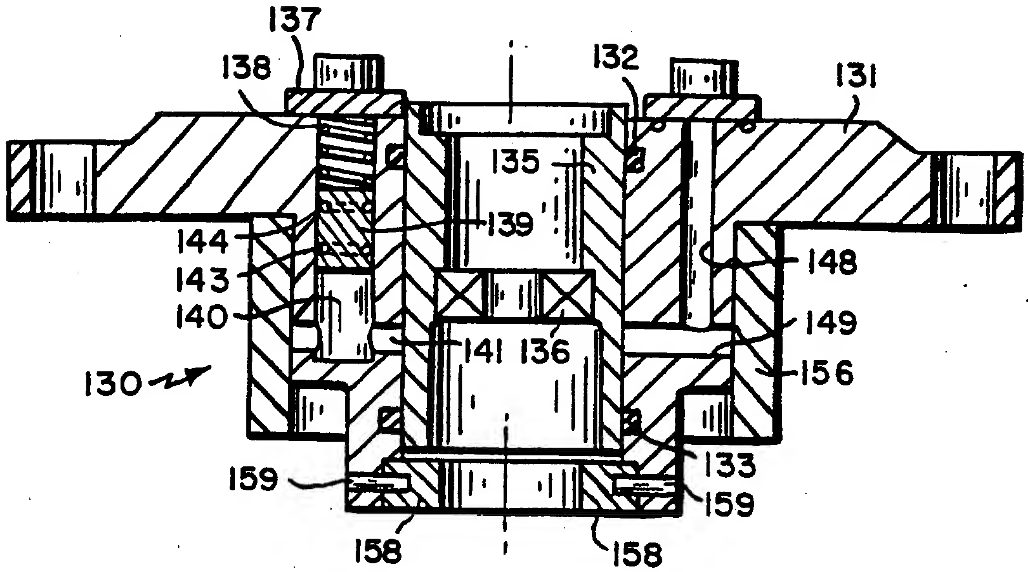

FIG. 5

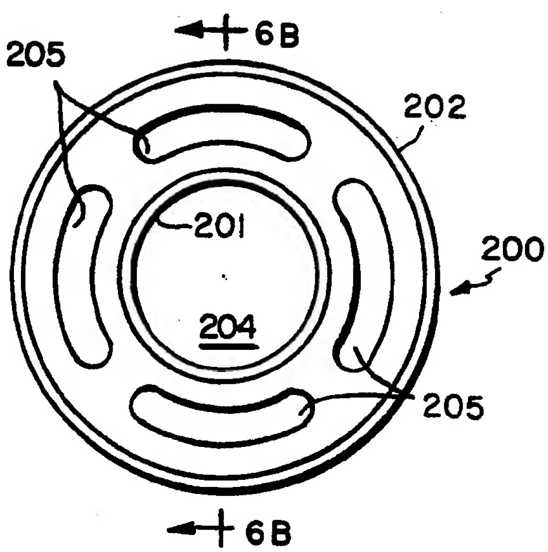

FIG. 6A

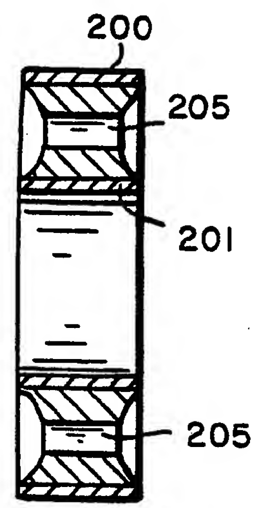

FIG. 6B

FLYWHEEL POWER SUPPLY

FIELD OF THE INVENTION

This invention relates to uninterruptible power supply systems and particularly to flywheel systems. More particularly, the invention relates to a magnetic levitation flywheel system.

BACKGROUND OF THE INVENTION

The telephone industry has long used lead acid batteries for back-up power to provide uninterruptible service. The typical telephone network sends signals over optical fiber from the central office to a remote terminal. There, the signals are converted from optical into electrical waves and demultiplexed onto individual copper lines bundled together as trunks for connecting to the home.

Each remote terminal supports approximately 1000 homes. The cable companies use a similar configuration, where signals are sent from the "head end" (cable company office) to remote terminals servicing approximately 500 homes. At the terminals, the signal is converted from optical to electrical waves for transmission over coaxial cable to individual subscribers. In both cases the remote terminal uses power provided by the local utility to carry the signal from the terminal to the subscriber, since fiber optic cable cannot carry electricity. To support the terminal during a utility outage, the phone or cable companies install a back-up power supply, typically an uninterruptible power supply which uses batteries as a power source.

It is desirable to eliminate batteries from these networks because of their limited life, poor reliability, and high maintenance requirements. These unfavorable attributes translate to high operating cost. Although commonly used valve-regulated lead acid batteries are referred to as "maintenance free," the batteries need continuous on-site monitoring and maintenance. The performance and life of batteries is temperature

dependent. Heat degradation occurs above 77°F (for every 15°F increase above 77°F the battery life is reduced by 50%). As a result, a battery schedule for 'change out' in five years only lasts two to three years. Batteries are also susceptible to "thermal runaway," which can result in the release of explosive hydrogen gas. In addition, batteries are not environmentally friendly due to lead content and are coming under increasingly strict environmental and safety regulations.

One replacement for batteries is the flywheel energy storage system. Existing systems for supporting high speed flywheels utilize either mechanical contact bearings or expensive and complicated magnetic bearing systems. Mechanical rolling element bearings have very limited life due to the high rotational speeds necessary for an effective flywheel energy storage system. Further disadvantages of mechanical bearings are noise, vibration, and poor reliability in the vacuum environment required to reduce windage losses of the high speed flywheel. A non contacting support with all control apparatus outside the vacuum solves these problems. Existing magnetic levitation systems typically are either expensive due to multiple axes of active control, or suffer from complicated magnetic structures when combining active and passive control.

U.S. 4,211,452 describes an inertia wheel more particularly adapted to space applications. It includes the combination of a peripheral type of motor with permanent magnet on the rotor and ironless winding on the stator. This structure limits speed due to stress. The current of the winding is switched electronically by an amplitude modulation system, associated to a reactance coefficient varying circuit, and reversal of direction of rotation of which is achieved by permutation of the control circuits. There are also provided bearings formed by a passive radial magnetic centering device and a redundant active axial magnetic centering device slaved to an axial rate detector. This device requires a permanent magnet and four control coils just for axial control.

U.S. 4,620,752 describes a magnetic bearing having position stabilization of a supported body which includes damping and aligning arrangement. An application of the magnetic bearing is illustrated showing a magnetic bearing system for a flywheel. This system requires combining two control coils with two rotating permanent magnets for each bearing.

It can be appreciated that new and improved magnetic levitation flywheel systems are desired, in particular, for back-up power supply systems to provide uninterruptible power supplies.

SUMMARY OF THE INVENTION

In accord with the present invention an uninterruptible power supply system is provided having a magnetic levitation flywheel module. The flywheel module comprises a flywheel rotor contained in a vacuum housing. The flywheel rotor is attached to a hub that is suspended from the housing by a frictionless axial magnetic bearing. Also, suspended by the magnetic bearing is the rotor of a permanent magnet motor/generator.

In accord with the present invention, a backup power supply comprises a controller and a flywheel module. The controller is configured to provide initial charge up of the flywheel to bring it up to standby speed, to keep the flywheel speed within a predetermined range at standby, to provide a predetermined voltage to the system for uninterrupted power supply, and to monitor the status of the flywheel module.

The flywheel module comprises a vacuum housing. In the housing is a flywheel and a motor/generator. The flywheel rotor and the motor/generator rotor are mounted on a common shaft and an active axial magnetic bearing being located to support the shaft for frictionless rotation. The bearing provides support, or axial lift, for the shaft, the flywheel and the motor/generator. The axial magnetic bearing is attached to the housing and provides, in combination with the motor/generator rotor, a flux path and magnetic field that provides a magnetic force to lift the motor/generator

rotor and the shaft on which it is mounted.

More particularly, the flywheel module comprises a vertical shaft on which the flywheel rotor is mounted along with the motor/generator rotor. Radially polarized permanent magnets are mounted around the motor rotor to provide at least four poles. A motor stator is fixedly mounted in relation to the rotor. Preferably, a passive radial magnetic bearing is located at one end of the shaft, more preferably at both ends. The passive radial bearing or bearings produce axial lift as well as radial centering. The axial lift offloads the active axial bearing and preferably lifts about 70% or more of the weight of the rotors. Typically, the passive bearings lift no more than 90% of the rotor weight. In one embodiment, the passive bearings lift 80% of the rotor weight.

In another embodiment, a damping device is positioned at one or, preferably, both ends of the shaft. One damping device comprises a plate member having a center bore and a sleeve positioned in the center bore and fitting around the shaft. The plate member has a chamber for containing a damping fluid. The chamber communicates with the center bore by means of a bore hole for fluid passage therebetween. The chamber also contains a spring and a plug, the plug being located between the spring and the fluid to transfer a force from the spring to the fluid or the fluid to the spring. As an alternative, an elastomeric ring can be used as a damping device.

The permanent magnetic motor/generator draws power from an electrical bus to spin-up the flywheel rotor to its steady state speed, transforming electrical energy into kinetic energy. The flywheel remains at its steady state rotational speed, drawing a nominal load from the bus. When power is required by the power supply system, the motor/generator transitions from a motor to a generator drawing energy from the flywheel for delivery to the bus.

The flywheel energy storage system (FESS) of the present invention

module of the present invention.

FIG. 9 is a block diagram illustrating the operation of the axial magnetic bearing.

FIG. 10 is a block diagram illustrating a system for detecting the balance status of a flywheel module of the present invention.

FIG. 11 is a state transition diagram for a controller for a flywheel module of the present invention.

DETAILED DESCRIPTION OF THE INVENTION INCLUDING PREFERRED EMBODIMENTS

A preferred flywheel device in accord with the present invention will be described with reference to the drawings. As illustrated in FIG. 1, a preferred flywheel device is configured as a module. A housing 45 contains the flywheel 15 which is suspended in the housing. The flywheel 15 is made with a flywheel rotor rim 16 which is an energy storage rim. The flywheel rotor rim 16 is mounted on a hub 17 which rotates at one and of an shaft 18. The module can be suspended from pins 40 to provide one axis of a two axis gimbal suspension.

A permanent magnet motor/generator 80 is located near one end of the shaft and an axial magnetic bearing 50 is located adjacent the motor/generator. The housing 45 surrounds the flywheel and preferably contains a vacuum with the vacuum level maintained by an ion pump (not shown).

In a preferred embodiment, a flywheel module 10 is constructed as illustrated in FIG. 3. A vacuum housing comprising housing cylinder 145, top cover 146 and bottom cover 147 surrounds the flywheel rotor 115. The flywheel rotor is mounted on a cylindrical support tube 116, which in turn is mounted on the vertical shaft 118. At the top of the cylindrical support tube 116 is positioned the motor/generator 180, a portion of which is conveniently used to mount the cylindrical support tube at its top end on the shaft.

The motor/generator assembly 180 is illustrated in further detail in FIG. 4. The motor/generator rotor is provided in two parts; an outer rotor cup 182 and an inner rotor cup 184, both of which are preferably made of iron and mounted on shaft 118 and which act as the return flux path for radially polarized permanent magnet pole pieces 187,188. The stator 190 is configured with a L-shaped cross section and is fixedly mounted to the top cover 146. The outer rotor cup 182 is configured at its top end to receive

and hold the cylindrical support tube 116.

On top of and adjacent to the inner rotor cup 184 is fixedly mounted an active magnetic bearing 120 having a coil 121 wound around an inner ferromagnetic core member 124 and sandwiched between the inner core member and an outer ferromagnetic flux member 125. The inner rotor cup 184 is made also of a ferromagnetic material. Thus, when a current is applied to the coil 121, a magnetic flux path is established through the inner ferromagnetic core member 124, the outer ferromagnetic flux member 125 and the ferromagnetic inner rotor cup 184 and an axial magnetic force is exerted on the shaft 118 through the inner rotor cup.

Radially polarized permanent magnets 187,188 are mounted to the outer rotor cup as alternately polarized pole pieces. As an alternative, a single row of radially polarized magnets can be used.

At the top end of the shaft 118 is a touchdown bearing comprising magnetic bearing assembly 150 and an annulus 158 providing a radial touchdown bearing, and a hardened surface 160 at the end of the shaft with a touchdown button 161 located in the top cover 146 assembly (see FIG. 4). Preferably, the annulus 158 and button 161 are made of a polyimide material, or the like. Also, in the top cover assembly is a damping system 130 (see FIGs. 4,5). An end plate 100 is mounted on top of the top cover 146. The end plate holds a fixed center rod 95 at the end of which is mounted touchdown button 161. A spring 98 is positioned within the end plate to provide an axial preload force. The spring engages sleeve 135 in which the end of shaft 118 rotates in ball bearing 136.

The magnetic bearing assembly 150 is a passive combination axial/radial magnetic bearing. A portion mounted to the shaft 118 comprises a cup member 151, preferably made of titanium, which is spaced axially from the inner rotor cup 184 by a spacer member 128. The cup member 151 is held in place by a retainer nut 152 threaded on the end of

the shaft 118. Inside the cup wall is fixed an axially polarized permanent magnet 155, which is held by suitable means such as epoxy. A second axially polarized permanent magnet 156 is fixedly mounted above the magnet 155. Both are polarized so the magnets attract, providing passive axial support for a portion of the weight of the rotor, preferably at least about 70%. The magnets in axial attraction also provide radial stabilization for the shaft 118. The permanent magnets 155,156 can be multiple annular rings of permanent magnet material.

The damping system 130 (see FIG. 5), preferably comprises a plate member 131 that attaches to top cover 146. A cylindrical sleeve 135 is positioned within a center bore in the plate member 131. An annulus 158 providing a radial touchdown bearing is held in the plate member 131 by pins 159. O-rings 132,133 provide a seal for the annular space between the cylindrical sleeve 135 and the bore wall. A ball bearing 136 is mounted within the sleeve to receive the top end of shaft 118. A chamber 140 is located in the plate member 131 in proximity to the central bore. A bore hole 141 communicates between the chamber 140 and the annular space between the cylindrical sleeve 135 and the bore wall. The chamber and annular space are filled with a damping fluid to damp radial vibration at the end of the shaft 118. In the chamber 140 is a plug 139 which exerts pressure on the damping fluid due to spring 138. The spring is held in place by damper cover 137. The plug 139 has o-rings 143,144 to provide a seal with the chamber wall. To provide damping fluid uniformly around sleeve 135, one or more additional bores 148 are used as fluid reservoirs and communicate through bore holes 149 to the annular space.

As an alternative, an elastomeric damper 200 can also be used to dampen radial vibration at the end of the shaft (see FIGs. 6A-6B). The elastomeric damper 200 is an annular ring of elastomeric material preferably between two rings 201,202 made of a non magnetic, hard material as shown in FIGs. 6A-6B. The sleeve 135 is positioned in the center hole 204 and the damper is fixedly mounted within the plate member